MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

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SIR DAVID GILL, K.C.B., F.R.S., PRESIDENT, in the Chair.

Percy Christopher Charles Billups, M.R.C.S., L.R.C.P., Barry Island, Glamorgan;
Selig Brodetsky, B.A., Trinity College, Cambridge;
Capt. Charles Edward Monro, R.N., Assistant Hydrographer, Admiralty; and
John Storey, Royal Observatory, Edinburgh,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended:—

Bruce H. Wade, Officer of the Egyptian Survey, Helwân Observatory, near Cairo, Egypt (proposed by H. H. Turner);
Dr. Milan Stefanik, Island of Tahiti, South Pacific (temporary address), (proposed by Sir David Gill).

The following were proposed by the Council as Associates of the Society:—

Dr. Artemis Bélopolsky, Observatory, Pulkovo, Russia;
Hisashi Kimura, International Latitude Station, Mizusawa, Japan; and
Professor W. H. Pickering, Harvard College Observatory, Cambridge, Mass., U.S.A.

Seventy presents were announced as having been received since the last meeting, including, amongst others:—

Four volumes of the Annals of Harvard College Observatory, including Professor Sampson's discussion of eclipses of Jupiter's satellites, 1878–1903; and Professor E. C. Pickering, Durchmusterung Zones observed with the meridian Photometer.

Also the 20th. and concluding volume of the National Edition of the Works of Galileo, presented by the Italian Government.

Investigations relating to the Spectra of Comets. By A. Fowler. (Plate 14.)

In a former paper * it was shown that the previously unknown bands which appeared in the photographic spectra of Comets Daniel (*d* 1907) and Morehouse (*c* 1908), and which were especially characteristic of the tails of these comets, were found in the spectra of carbon compounds at a pressure of about 0·01 mm. Several matters, however, remained for further investigation, and the experimental work has been continued.

It has been especially sought to ascertain the precise carbon compound which gives rise to the new spectrum, and to determine as far as possible the conditions under which it can separately exist. It was also desirable to extend the measurements of the bands into the green and ultra-violet, and to endeavour to find a brighter source of the spectrum for this purpose. A more extended series of experiments was also undertaken in order to determine the relation between the new spectrum and the various series of bands recorded by Deslandres in his important researches on the ultra-violet spectra of compounds of carbon.†

Most of the results depend upon photographic records of the various spectra, but visual observations were also constantly made, a Hilger one-prism quartz spectrograph and a wave-length spectroscope being chiefly employed.

For convenience of reference, the low-pressure spectrum corresponding with the bands of Comets Daniel and Morehouse will be called the "tail spectrum" in what follows.

Probable Origin of the Tail Spectrum.

In the experiments which have been made in the hope of throwing further light on the origin of the tail spectrum, discharge tubes provided only with external electrodes were employed, in order to reduce the possible sources of contamination of the gas

* *M.N.*, vol. lxx. p. 176 (1909).

† *Comptes Rendus*, vol. cvi. p. 842 (1888), vol. cxxxvii. p. 457 (1903), and vol. cxl. p. 917 (1905).

under investigation. These tubes were usually about three-quarters of an inch in internal diameter, and were viewed end-on, through a quartz window attached by sodium silicate. The sparking distance was about 8 inches, and the discharge was usually that given by a 6-inch coil.

Beginning with an empty tube of this kind, the spectrum first observed as the pressure was reduced was that of nitrogen, but at lower pressures, after continued sparking, the "carbonic oxide" bands (561, 519, 483, etc.) were observed; and finally, at the lowest stages of luminosity, the tail spectrum was seen as in the previous experiments. After washing out the tube with air which had been freed from carbon dioxide and moisture, however, it was easy to obtain a vacuum such that the whole tube was strongly fluorescent, and no gas spectrum, other than a very feeble one due to mercury vapour, remained visible. It would seem, then, that any subsequent spectrum might fairly be considered to be due to the gases introduced into the tube.

The following is a brief statement of the results obtained with different gases and vapours, in so far as they bear on the origin of the bands of the tail spectrum.

Carbon monoxide (CO). — The gas was prepared from sulphuric and formic acids, and was passed over caustic potash and phosphoric anhydride to remove any traces of carbon dioxide and moisture. The degree of purity obtained in some cases was such that no indications of water vapour, hydrogen, or nitrogen could be detected spectroscopically. At the pressure giving maximum luminosity, the carbonic oxide bands were very intense, and the strongest bands of the tail spectrum were just perceptible. With reduction of pressure, and consequent reduction of luminosity, there was a gradual increase in the intensity of the tail bands, and a corresponding decrease in that of the carbonic oxide bands. The tail spectrum was invariably best developed at the lowest pressures giving any luminosity, and was most nearly isolated at the ends of the tube outside the direct path of the discharge.

Carbon dioxide (CO_2).—The phenomena as regards the tail bands were almost identical with those observed in the case of the monoxide, but the spectrum was generally accompanied by other lines or bands which may possibly have been due to oxygen.

Petroleum (C_nH_{2n+2}).—The vapour was obtained directly from the liquid and passed over potash and phosphoric anhydride. After several washings, during which the ordinary and ultra-violet bands of carbonic oxide were gradually reduced in intensity and finally eliminated, the vapour was obtained so pure that only the characteristic hydrocarbon band 431 and the lines of the primary and secondary spectra of hydrogen were observed. Even at the lowest pressures, not the slightest trace of the tail spectrum could be found, but it immediately became visible, together with the carbonic oxide bands, on the admission of a minute quantity of air.

Benzene (C_6H_6).—The phenomena were apparently identical with those observed in petroleum.

Carbon bisulphide (CS_2).—This yielded no information, as it showed no bands of carbon under these conditions of observation, but only a spectrum due to sulphur.

Cyanogen (C_2N_2).—As prepared in the ordinary way from mercuric cyanide, the carbonic oxide bands always became visible after the gas had been decomposed by the passage of the spark, and the tail spectrum followed when the pressure was sufficiently reduced. By taking very special precautions, however, Baly * has shown that pure cyanogen does not exhibit the carbonic oxide bands, and it may be presumed that the tail spectrum would also fail to appear.

The foregoing observations appear to give satisfactory evidence that the tail spectrum is produced by an oxygen compound of carbon. It is less certain whether the gas in question is carbon monoxide or carbon dioxide, but the fact that the tail spectrum can be most nearly isolated from the former suggests that it is most probably due to the monoxide.

Conditions of Appearance of the Tail Spectrum.

Numerous experiments have been made on carbon monoxide with tubes of various forms, in order to determine the conditions under which the tail spectrum makes its appearance.

Capillary tubes have been found unsuitable, as the required spectrum only appears feebly, as part of a complex spectrum, even at the lowest workable pressures. In a series of connected tubes containing gas at the same pressure throughout, the relative intensity of the tail spectrum was roughly in direct proportion to the diameter of the tube. Its appearance was accompanied by that of the two negative series of bands in the ultra-violet described by Deslandres, and by a diminished intensity of the positive bands which appeared strongly at higher pressures.†

Interesting results were obtained by the use of a discharge tube provided with a side tube closed by a quartz window, so that the kathode could be observed in its own plane, with but little interference from the positive column. It was found that the tail spectrum began to appear on the kathode when the pressure was 2 or 3 mm., and, as before, the ultra-violet negative bands appeared feebly about the same time. At the anode, the tail bands did not appear at this pressure, but at the lowest pressures they appeared, with the negative bands, in all parts of the discharge.

* *Phil. Mag.* (6), 2, p. 386 (1901).

† One of Deslandres' negative series consists of about 16 flutings, degraded to the red, lying between 2190 and 2800; the bands of the other negative series are also degraded to the red, and extend from about 3200 to 4000. A positive series, degraded to the red, occupies the region 2100–2600; and another, degraded to the violet, extends from about 2400–2900. Most of these are unfortunately beyond the limit for which our atmosphere is transparent, and are out of range in cometary investigations

Attempts were made to produce luminosity in the gas at pressures lower than 0·01 mm. by the use of a hot lime kathode, and, under these conditions, luminosity was obtained after the discharge had ceased to pass from the cold kathode; the pressure was estimated at about 0·005 mm., but even then the carbonic oxide bands (561, 519, etc.) had not quite disappeared.

It may be of interest to mention that the tail spectrum was obtained in a nearly isolated state by the use of a burnt-out incandescent electric lamp provided with external electrodes of tinfoil. In most of these bulbs, however, the vacuum is too high for the production of luminosity in this way. The carbon monoxide in this case is probably produced in part by the combustion of the carbon filament in a limited supply of oxygen, and some is doubtless liberated from the walls of the bulb when the discharge is passed.

The observations indicate that the tail spectrum is best developed in a comparatively free space by gentle discharges at the lowest pressures giving sufficient luminosity for observation (about 0·01 to 0·005 mm.), and that it is associated with the ultra-violet series of negative bands. At the low pressures necessary for its approximate isolation, the kathode glow fills the whole discharge tube, and the luminosity may perhaps be regarded as being chiefly due to the bombardment of the molecules of the gas by kathode rays.

Wave-lengths and Structure of the Tail Bands.

Apart from the slightly better results obtained by the use of a hot lime kathode, attempts to produce a brighter source of the tail spectrum—including the method of electro-magnetic electrodeless discharge — have so far been unsuccessful. Nevertheless, additional bands in the green and ultra-violet have been identified as belonging to the spectrum, and their positions have been determined. The wave-lengths of these bands, together with those previously tabulated, are shown in the appended table. The table also gives the oscillation frequencies, and frequency intervals between the bands, from which it will be seen that nearly all of the bands fall into two regular series of doublets. In each of the two series the strongest bands are those near the middle. A possible third series is at present represented by only one double band.

As described in the previous paper, the tail bands, when viewed with small dispersion, have the appearance of broad double lines, with a slight shading towards the red. With a more powerful spectrograph, the shadings are clearly resolved into lines, as is the case with flutings in general. The lines proceeding from the more refrangible member of each pair are relatively weak, but in the stronger bands they can be traced about halfway across the interval between the components, while the stronger shadings from

the less refrangible members extend over a space about equal to this interval.

It will be understood that since the heads of the bands are groups of very close lines, the positions assigned will only be comparable with those derived from photographs giving insufficient purity of spectrum to permit their resolution.

Wave-length.	Intensity.	Oscillation Frequency.	Frequency Intervals.
5510	2	18149	
5473	2	18272	
5078	5	19692	1534
5049	5	19806	
4715·0	3	21209	1523
4688·5	3	21329	
4570·5	5	21879	
4545·4	6	21998	
4276·0	10	23386	1514
4253·2	8	23512	
4020·4	8	24874	1480
4001·3	6	24992	
3797·6	6	26333	1456
3781·0	6	26448	
3707·5	3	26972	
3693·0	3	27078	1430
3602·0	3	27762	
3587·0	2	27878	
3429·0	2	29163	1405
3415·0	2	29283	

There are indications of another faint band about 4916, 4887 which would be associated with the first series; and there is possibly another pair about 3907, 3891.

Further comparison with Comets Daniel and Morehouse.

It has already been shown that the bands of the foregoing table from 4715 to 4001 correspond precisely with those especially developed in the tails of Comets Daniel and Morehouse. The ultra-violet bands must also necessarily have been present, and there is no difficulty in identifying the first three of them with

the bands recorded by Evershed at the approximate positions 378, 369, and 358 in Daniel's Comet.

In the case of Morehouse's Comet, however, the identification of some of the bands is more difficult in consequence of the presence of the kathode band of nitrogen 3914 (as first shown by Deslandres), and the admittedly not very exact wave-lengths available. Other kathode nitrogen bands at 3577 and 3371 must also have been present in this comet. Deslandres' wave-lengths of the comet bands are $\left.\begin{matrix}3799{\cdot}2\\3782{\cdot}7\end{matrix}\right\}$, 368, 357, and 337, the last three being determined only by extrapolation. The first pair and 368 may be certainly identified with bands of the tail spectrum of carbon monoxide, but it is not possible to determine whether the remaining two belong to nitrogen or to the series of tail bands. The kathode nitrogen band at 357, however, is relatively weak, and the comet band 357 may very well have been identical with Evershed's 358, which must certainly be assigned to the tail series in the case of Daniel's Comet, as the nitrogen band 3914 was not then observed.

Brorsen's Comet 1868.

The present investigation is very suggestive in connection with the "anomalous spectra" recorded by Sir William Huggins in his earliest observations of comets.

In Brorsen's Comet of 1868 the spectrum was observed to consist of three bands which were considerably different in position from those of the Swan spectrum of carbon which have since most frequently appeared. A general displacement of the bands towards the red would bring them into fair accordance with the carbon bands, and it has been suggested that a large systematic error must have been made in fixing their positions. The account of the observations, however, leaves little room for doubt as to their general accuracy, and the appearance of the bands themselves was notably different from that of the Swan bands, as shown both by the description and illustrations. From observations with a rather wide slit, the comet bands are described as resembling expanded lines, such as the F line in the spectrum of hydrogen at atmospheric pressure; and the middle band is described and illustrated as a double. The bands of the Swan spectrum, on the other hand, are distinct flutings, sharp on the red edge.

The positions of the bands were shown diagrammatically on the arbitrary scale then in use, but Sir William Huggins has very kindly communicated further information on this point. He writes: "In 1882 I went over the observations and measures made in 1868, and I found for the brightest band *about* 5070. For the fainter bands the measures are probably less certain, a wide slit having been used; they came out 4650 and 5440. 'Middle band distinctly double.' I believe the wave-length of the middle band is not far from the truth."

The appearances and positions of these cometary bands

suggests that at its return in 1868 the spectrum of Brorsen's Comet was very similar to that of Comet Morehouse, differing chiefly in the greater development of the "tail spectrum" of carbon monoxide in the vicinity of the nucleus. The bands would in that case be identified as follows:—

Brorsen's Comet 1868 (Huggins).	Low-pressure Carbon Monoxide.
5440±	5510 5473
5070 (double)	5078 5049
4650±	4715 4689

The differences in wave-length in the case of the blue and yellow-green bands are probably not too great to invalidate the identification, considering the general faintness of the spectrum of the comet.

It is possible also that the spectra of Comet I. 1866 and Comet II. 1867 may be explained by supposing them to have been faint examples of the Morehouse and Brorsen type. Referring to his observations of these comets, Sir William Huggins wrote:* "The spectra of these objects, so far as their feeble light permitted them to be observed, appeared to be very similar. In the case of each of these comets, the spectrum of the minute nucleus appeared to consist of a bright line between *b* and F, about the position of the double line of the spectrum of nitrogen" (*i.e.* about 5006). It is very improbable that this bright line could have been the carbon fluting close to *b*, but it may have been the low-pressure carbon monoxide band 5049, 5078. Sir William Huggins has informed me, however, that he does not think the observations are sufficient to show if the spectra of these comets resembled that of Brorsen's Comet or not.

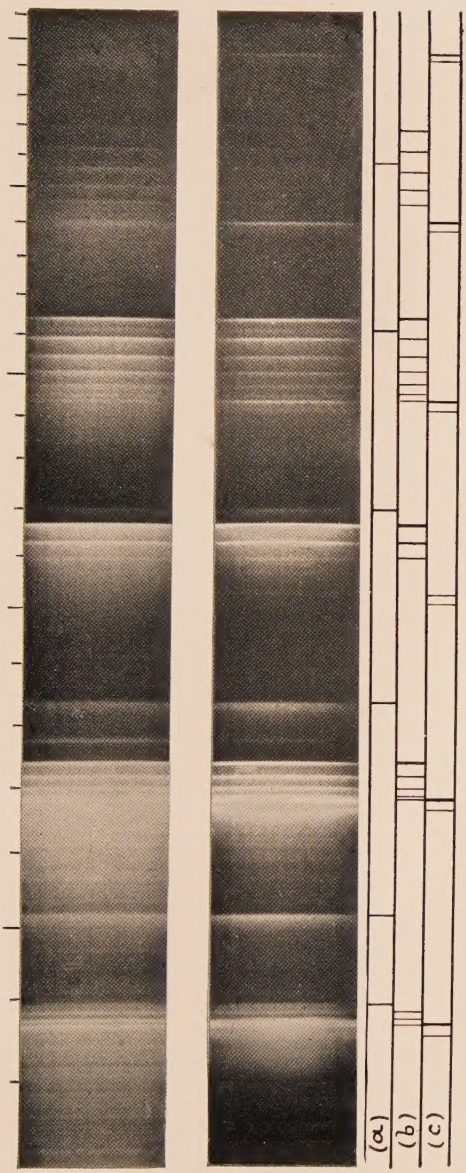
If the foregoing interpretation of the spectrum of Brorsen's Comet be correct, it would appear that in some comets the greater part of the luminous gases of the head may have a density as low as that of the tail of Morehouse's Comet.

A New "High-pressure" Spectrum of Carbon Monoxide.

In the course of a general investigation of the spectra of carbon compounds, a new band spectrum of *carbon monoxide* has been detected,† which seems likely to be of considerable interest in relation to some features of cometary spectra. The principal facts

* *Proc. Roy. Soc.*, vol. xvi. p. 386.

† The two most refrangible bands of this spectrum were possibly obtained by Deslandres and D'Azambuja in 1905 (*Comptes Rendus*, cxlv. 919). Bands at 4680·62? and 4372·57? are mentioned, but their intensities and positions were doubtful on account of their superposition on bands of the Swan spectrum. These observers, however, did not describe the complete series of bands, and perhaps did not obtain them very clearly.



SPECTRA OF CARBON MONOXIDE

(1) Without jar at pressure of 100 mm. (2) With jar at slightly reduced pressure. (*a*) Ångström's "CO" bands. (*b*) "Swan" bands. (*c*) "High-pressure" bands.

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relating to this series of bands may be briefly summarised as follows:—

(1) The spectrum has been obtained from carbon monoxide, but not from carbon dioxide, petroleum, benzene, or cyanogen, or from carbon monoxide mixed with air, under precisely similar conditions of experiment. The bands may therefore be provisionally regarded as characteristic of carbon monoxide.

(2) When best developed, as in a capillary tube with the pressure so high that the discharge will scarcely pass (about 100 mm. in the tube employed), or on the kathode of a wide tube at about 20 mm. pressure, these bands are the most conspicuous feature of the spectrum. As the pressure was reduced below this, the bands rapidly vanished, and they were not found in the spark at atmospheric pressure or at a pressure of half an atmosphere, either with or without capacity.

(3) The new bands are usually accompanied by the Ångström bands of carbonic oxide (561, 519, etc.) and by those of the Swan spectrum, though both the latter may be relatively faint. They are usually found in all parts of the discharge, but there is some evidence that they should be classed with the positive series of bands.

(4) The six bands composing the series are all situated in the visible spectrum, and are degraded to the violet. They closely resemble in appearance the kathode bands of nitrogen at low pressures. With small dispersion they have the appearance of sharp double lines, of which the less refrangible components are considerably the brighter; but with increased dispersion they are somewhat broadened, and show signs of resolution.

(5) Provisional wave-lengths and estimated intensities of the bands are given in the appended table.

λ.	Int.	λ.	Int.
6441	4	5030	2
6420	2	5015	1
5897·5	6	4679	10
5878	3	4663	4
5431	5	4365	5
5413	2	4353	2

It will be observed that the second band encloses the D lines of sodium, wave-lengths 5890·19 and 5896·16. The frequency intervals show that the first four bands form a regular series, and the last two may possibly form part of the same series.

The photographs of capillary tube spectra reproduced in Plate 14 will serve to show the positions of the high-pressure bands in relation to the Ångström carbonic oxide bands and those of the Swan spectrum. The red end, however, is not represented with sufficient intensity, and the high-pressure bands as a whole have not the greatest possible relative intensity. No. 2 shows the

normal appearance of the Swan bands, and No. 1 the modifications introduced by the superposition of the high-pressure bands.

The High-pressure Bands compared with Comets.

The probable presence of the "high-pressure" bands in comets is suggested by the fact that the point of maximum intensity in the blue Swan group beginning at 4737 has often been recorded at 468 or thereabouts. Sir Norman Lockyer has collected the earlier observations referring to this matter, and has suggested that an explanation might be given by the observation that at pressures giving maximum conductivity in Geissler tubes, the luminosity of the blue band has a very decided maximum about 468.* The maximum here referred to, however, is less defined, and less pronounced, than that which is given by the superposition of the new band spectrum on the Swan spectrum, and the latter combination accords better with some of the photographic records of cometary spectra which have become available since Lockyer's investigations were made. Moreover, the photographs suggest the probable presence of the second blue band of the high-pressure spectrum at 436 It will suffice to refer to the photographic spectra of Borelly's Comet 1903 and of Comet *a* 1910, as obtained by Deslandres,† in support of this interpretation. The numbers in brackets in the table which follows are estimated intensities.

"High-pressure" CO.	Borelly's Comet 1903.	Comet *a* 1910.	Remarks on Comet Spectra.
(Swan) (3)	4736·9 (4)	4737·5 (5)	"Swan" band 4737·2
,, (3)	4715·2 (3)	4716·5 (6)	,, ,, 4715·3
,, (2)	4697·1 (2·5)	...	,, ,, 4697·6
,, (2)	...	...	,, ,, 4684·9
		4686·5 (8)	Swan 4697·6, 4684·9 combined with CO 4679
4679 (10) 4663 (4)	4681·5 (8)	...	Swan 4684·9 combined with CO 4679
(Swan) (1)	...	438	(Swan) 4381·9
,, (1)	4371·4 (1)	4366·5‡ (2)	,, 4371·3
4365 (5)	|	|	,, 4365 + CO 4365
4353 (2)	4356·2	435	

Further observations with instruments of greater separating power are desirable, but it can scarcely be doubted that the abnormal intensity of the more refrangible part of the blue band of the Swan spectrum in these two comets was due to the presence of the new high-pressure spectrum of carbon monoxide. If this

* *Meteoritic Hypothesis*, p. 177 (1890).
† *Comptes Rendus*, cxxxvii. 393 (1903), cl. 653 (1910).
‡ Described as a distinct condensation in band 435–438.

be granted, it must follow that the less refrangible high-pressure bands must also have been present in all the comets which have shown the blue band in this way. The existing records of comet spectra, however, do not furnish much evidence on this point; visual observations are difficult, and photographs rarely depict the green and red parts of the spectrum.

A maximum at 544 or thereabouts, falling in the tail of the yellow-green Swan band, has been occasionally noted, and this may possibly be identified with the high-pressure band 543, if the maximum at 468 was shown at the same time. This was probably the case, for example, in Comet III. 1881 as observed by Copeland.*

There are at present no observations of comets from which the presence of the yellow and red bands of the high-pressure spectrum can be probably inferred, but narrow bands such as these might easily be overlooked on the background of continuous spectrum, unless, as in the case of the yellow-green and blue bands, attention is drawn to them by their effect in modifying the normal appearance of the Swan spectrum. In the presence of sodium lines, a resolving power greater than is usually employed in the observation of comet spectra would be required to distinguish the bright component of the yellow band from the D_1 sodium line (see also p. 494).

There is at least sufficient evidence of the occasional occurrence of the high-pressure bands to demand their careful consideration in future discussions of cometary spectra.

Further remarks on the Spectra of Comets' Tails.

Apart from Comets Daniel and Morehouse, very little is known of the spectra of comets' tails, and there is very little ground for the prevalent impression that the most usual spectrum is the Swan spectrum of carbon (often called the hydrocarbon spectrum). Bredichin's suggestions as to the composition of the three types of tails are of course purely hypothetical, but even so careful an author as Professor Young has stated † that "tails of the second type, which are brightest and most usual, do show a hydrocarbon spectrum throughout their entire length, and so far confirm this view."

The only observations which can possibly be considered to have indicated a "hydrocarbon" tail are those of Comet *b* 1881 which was of Bredichin's second type. In this comet Professor Young

* *Copernicus*, vol. ii., plate vi. The yellow-green band is drawn with maxima about 563, 558, and 544, of which the first two correspond closely with the heads of the Swan band at 5635·4 and 5585·5, while the third may represent the high-pressure band 5431. This appearance is well reproduced in one of the photographs of the high-pressure spectrum, in which 563, 558, and 543 are of nearly equal intensity, while the intermediate heads of the Swan band are relatively weak. (Plate 14, No. 1.)

† *General Astronomy*, art. 372.

himself, on June 29 and July 1, only traced the bands to a distance of about 20′ from the nucleus,* but Vogel stated that on June 30 the band spectrum was clearly visible to the very end of the tail.† Vogel's observations, however, were made with a spectroscope of small dispersion, and the account which he gives is too brief to assure us that the bands of the tail were identical with those of the head of the comet. If the tail of this comet had resembled that of Comet Morehouse, the bands in the visible spectrum at 549, 507, and 470 would not have been easily distinguished from the bands of the Swan spectrum with a small spectroscope.

The evidence as to the presence of the Swan bands of carbon in the tails of comets cannot therefore be regarded as conclusive, but it may be pointed out that Bredichin's views would not be affected by the substitution of carbon monoxide for the hydrocarbons acetylene and olefiant gas, as the molecular weights of these compounds are nearly identical.

The only other comet which seems to have been spectroscopically observed at any considerable distance from the head is the great Comet of 1882, the tail of which was also of the second type, but appears to have given a different spectrum. When near perihelion (September 17) the sodium lines were visible in the head, and Sir David Gill stated ‡ that "with a direct-vision prism, whose plane of dispersion was placed at right angles to the direction of the comet's tail, a complete yellow monochromatic image of the head and of a great portion of the tail was easily visible for a week after perihelion." In reply to an inquiry as to whether he could recall the extent of the yellow image, Sir David Gill has kindly written: "My recollection is very faint, and I can give only an impression, which may not be exact; but I think I am safe to say it could be seen for 3 or 4 degrees from the nucleus."

Although there can be no question as to the identity of the sodium lines in the *head* of this comet, the case may be different with regard to the *tail*. It is difficult to conceive of sodium vapour existing as such to any great distance from the nucleus (probably some millions of miles, as indicated by Sir David Gill's observation), and a possible alternative origin for the yellow image of the tail is suggested by the "high-pressure" spectrum of carbon monoxide to which reference has been made. The yellow band of this spectrum is very nearly coincident with the sodium lines, and would probably be the most conspicuous of the bands in the more visible parts of the spectrum. Under the specially active conditions exhibited by this comet when near perihelion, carbonic oxide of sufficient density to produce the high-pressure spectrum may have been thrown to a great distance from the nucleus, but careful observations of the yellow band with a slit spectroscope, and indications of the other bands, would be necessary to determine whether this was the case. The suggestion may be of use,

* *Amer. Jour. Sci.*, 3rd. series, xxii. 136.
† *Ast. Nach.* 2395. ‡ *M.N.*, vol. xliii. p. 21.

however, when improved records of cometary spectra become possible.

Comet *a* 1910 appears to have resembled the great Comet of 1882 very closely in its spectroscopic features, but it was not well placed for observation, and throws no additional light on the above suggestion with regard to the yellow radiation from the tail.

[For the sake of completeness, it should be added that in the great Comet of 1882, after the most active stage was passed, the spectrum of the tail was stated by Ricco to be continuous throughout its whole length, the carbon bands only being given by the nucleus and a region about 5′ round it.* In the case of Comet *a* 1910 also, after the disappearance of the sodium lines from the nucleus (January 31), the spectrum of the tail was traced to a distance of 1 degree by Wright, and found to be continuous. Mr. Wright suggests that this apparently continuous spectrum may have been the fluorescence spectrum of sodium vapour.†]

Concluding remarks.

The foregoing investigations suggest that carbon monoxide may be the most abundant and most constant of the gaseous constituents of comets. When this gas is of sufficient density, it readily yields the Swan spectrum, which is the most usual feature of the spectrum of a comet's head, while at very low pressures it reproduces the spectra of those tails about which we have the most definite information. If there be a small admixture of nitrogen, the cyanogen bands 3883 and 4216 appear quite strongly in addition to the Swan bands, if the gas be of considerable density, exactly as they do in the heads of comets; the nitrogen bands do not then appear, and the first two heads of the 3883 band of cyanogen are strongly marked. On the other hand, when the density is low, the same mixture barely shows the cyanogen bands, and the kathode nitrogen bands then appear with the low-pressure bands of carbon monoxide, as in the tail of Comet Morehouse. The true characteristic band of hydrocarbons at 431 is only an occasional feature of the spectra of comets, and hydrocarbons may therefore be regarded as a variable constituent. It should be mentioned, however, that the ordinary "carbonic oxide" bands of Ångström and Thalén (561, 519, etc.), which occur in the laboratory spectra of carbon monoxide, have not been very definitely recorded in comets, and a satisfactory explanation of this has yet to be found.

It may be of interest to point out that the mean density of the gas composing the tail of a great comet cannot be so great as that of the carbon monoxide in a vacuum tube which reproduces the Morehouse tail spectrum, as an impossible total mass of the comet would follow. A volume of gas equal to that of the Sun, having the density of carbon monoxide at a pressure of 0·005 mm., would

* *Observatory*, vol. v. p. 324. † *Lick Obs. Bull.*, No. 174.

have a mass of about $\frac{1}{500}$th. of the Earth's mass, and the tails of some comets have apparently occupied thousands of times the volume of the Sun.

An obvious partial explanation of the discrepancy is to suppose, as other considerations have indicated, that the tail does not consist of a continuous mass of rarefied gas, but is either hollow or consists of thin sheets and streams. It is possible, of course, that gas of much lower density than that stated can be made luminous by the source of cometary illumination, but it is not known whether the spectrum would remain the same when the density was very greatly reduced.

The actual source of the luminosity of the tail of a comet is still very uncertain, but there can be little doubt that it is of electrical origin. In view of the mode of production of the spectrum in our laboratories, it may be permissible to suppose that the tenuous gas is illuminated by negatively charged particles issuing either from the head of the comet or from the Sun. The occurrence of the negative bands of nitrogen in Comet Morehouse, and in the spectrum of the aurora, is in fact regarded by Deslandres as an indication that kathode rays, or some analogous rays, are really emitted by the Sun.* This view, however, would seem to demand more constant displays of terrestrial auroræ, unless the gases in comets' tails are more sensitive to the kathode rays than are the rarefied gases in the upper reaches of our atmosphere. The direction of the tail appears to be determined chiefly by a sola: repulsive force, but it may be that its luminosity arises from electrical effects originating mainly in the head of the comet. Professor Newall's suggestion that the luminosity of the tail may be produced by repelled dust particles, in rapid motion through gases already diffused in interplanetary space, also demands careful consideration.

The experimental work forming the basis of the present paper has been somewhat laborious and exacting, and I have pleasure in acknowledging the valuable assistance which has been so willingly given by Messrs. H. Shaw and A. Eagle.

* *Comptes Rendus*, cxlviii. p. 809, 1909.

Places of Halley's Comet, 1909–1910, *deduced from photographs taken at the Radcliffe Observatory, Oxford.* By Dr. A. A. Rambaut, F.R.S., Radcliffe Observer.

On November 5, 1909, the large refractor of the Radcliffe Observatory was first directed to Halley's Comet. On that occasion, though very faint, it was detected without much difficulty in the 18-inch telescope by four observers, as described in "Observers' Remarks" below. An approximate position for the comet was deduced from readings of the circles of the equatorial, but no photograph was taken.

The photographs discussed in this paper were obtained with the 24-inch telescope of the equatorial. The focal length of this instrument is 22 feet 6 inches, and the scale of photographs taken in the principal focus is accordingly very approximately 30″ to 1 mm. The openness of the scale and the excellent character of the images enable the measures to be made with a high degree of precision.

The driving clock was on all occasions regulated to follow the motion of the comet. On November 7 and 10, while the comet was still relatively very faint, the guiding was effected by means of a neighbouring star which was kept (by the slow motions) on the intersection of micrometer-wires which were moved relatively to the photographic plate at short intervals in accordance with the computed motion of the comet. On and after November 17 the guiding was effected with fixed wires on the nucleus of the comet itself.

At first a continuous exposure was given, and the measures of the comparison stars were made to both extremities of the corresponding star-trails. The mean of such measures for any particular star combined with similar measures for the nucleus of the comet will then give the position of the latter relatively to the star at the time of mid-exposure, assuming that the motion of the comet is sensibly uniform during the exposure. In the early part of November, while the motion in right ascension was small and the altitude considerable, this method proved quite satisfactory, but as the motion in R.A. became greater, and when the photographs had to be taken at greater zenith distances, it was found more convenient to interrupt the exposure in the middle for such an interval as would make a short but distinct break in the star-trail. Thus on November 22 two exposures of an hour each were given with an interval of two minutes during which the plate was covered. The star-trails therefore consisted of two portions AB and CD, thus: A B C D. The measures were made to the extremities B and C, and their mean accordingly gives the position of the star at the time corresponding to the middle of the break.

On some occasions the exposure was interrupted by clouds, so that the above symmetrical arrangement could not be fully carried out, but in all cases the measurements were made to two points on the trail which correspond to definitely known epochs. The time given in the second column of the table under the heading G.M.T. (to which the resulting place of the comet corresponds) is thus ascertained.

On December 31 three photographs were taken on the same plate with total exposures of forty, twenty, and ten minutes respectively. In the last the image was found to be too faint for accurate measurement, and was accordingly omitted, but the other two were independently reduced, and the resulting places for the comet are given separately in the table.

The plates were measured in the Grubb measuring-microscope, a description of which will be found in the *British Association Report* for 1905, pp. 335–337. The first two plates—those of November 7 and 10—were measured by myself, after which this work was handed over to Mr. Barrett, who effected all the subsequent measures.

For the most part the places of the comparison stars were taken from the *Astrographic Catalogue*, six such stars, distributed as symmetrically as possible around the comet, being in general selected. The measured rectangular co-ordinates (x_1, y_1) on the Oxford plate will then be connected with those of the *Astrographic Catalogue* (x_2, y_2) by relations of the form

$$x_2 = ax_1 + by_1 + c + lx_1^2 + mx_1y_1$$

and

$$y_2 = dx_1 + ey_1 + f + lx_1y_1 + my_1^2,$$

where a, b, c, d, e, f, l, and m are constants. Having ascertained that the terms of the second order in these expressions would in no case affect the resulting place of the comet by as much as one-twentieth of a second of arc, I have entirely neglected them, and the simple linear relations between x_1, y_1 and x_2, y_2 have been adopted. The constants were determined for each plate by the method of least squares, and when these were applied to the Oxford measures of the comet we obtained the co-ordinates of the comet's position in the *Astrographic Catalogue*. From these the R.A. and Decl. of the comet referred to the equator and equinox of 1900·0 were deduced by means of the reduction formulæ given in the catalogue, which, by the application of the precession and the ordinary star corrections, were brought up to the time of observation so as to afford the apparent R.A. and N.P.D. given in the fourth and seventh columns of the table.

Places of Halley's Comet, 1909–1910, *deduced from photographs taken at the Radcliffe Observatory, Oxford.*

Date.	G.M.T.			Local Sidereal Time.			Apparent R.A. of Comet.			Corr. for Parallax in R.A. (p).	Log. $p\times\Delta$.	Apparent N.P.D. of Comet.			Corr. for Parallax in N.P.D. (q).	Log. $q\times\Delta$.	Observers.		Ref.
1909.	h	m	s	h	m	s	h	m	s	s		°	′	″	″				
Nov. 7	12	53	15	3	54	30	5	40	0·44	−0·09	9·2286	73	10	44·2	−2·7	0·7129	A.R.	G.R.	(*a*)
10	13	48	1	5	1	15	5	33	16·59	−0·03	8·7213	73	13	21·5	−2·7	0·7004	W.	B.	(*b*)
17	12	20	48	4	1	24	5	15	2·98	−0·07	9·0789	73	22	48·6	−3·0	0·7077	W.	B.	(*c*)
18	11	50	48	3	35	15	5	12	8·87	−0·09	9·1920	73	24	38·3	−3·1	0·7130	R.	H.B.	(*d*)
22	12	30	13	4	30	33	4	59	20·26	−0·03	8·6780	73	34	4·0	−3·2	0·7039	W.	B.	(*e*)
23	14	0	59	6	5	30	4	55	43·59	+0·07	9·0562	73	37	6·4	−3·2	0·7094	R.		(*f*)
Dec. 4	10	36	15	3	23	35	4	13	52·31	−0·06	8·9117	74	24	47·7	−3·6	0·7146	R.	H.B.	(*g*)
18	10	8	22	3	50	49	3	12	36·78	+0·05	8·7894	76	15	18·1	−4·0	0·7318	R.	H.B.	(*h*)
31	7	46	14	2	19	33	2	20	35·61	0·00	...	78	21	4·6	−4·0	0·7500	R.	B.	(*i*)
31	8	22	59	2	56	24	2	20	29·85	+0·04	8·7628	78	21	17·5	−4·0	0·7511	R.	B.	(*j*)
1910.																			
Jan. 10	9	9	57	4	22	55	1	48	17·28	+0·16	9·3635	79	47	37·3	−4·0	0·7785	R.	H.B.	(*k*)
12	7	14	33	2	35	5	1	43	1·86	+0·06	8·9183	80	1	43·7	−3·9	0·7667	R.	H.B.	(*l*)
19	7	25	45	3	13	55	1	26	7·95	+0·11	9·2228	80	46	8·0	−3·8	0·7782	R.	H.B.	(*m*)
Feb. 2	8	11	5	4	54	34	1	1	20·78	+0·18	9·4942	81	42	17·6	−3·7	0·8050	R.	H.B.	(*n*)
3	8	36	28	5	23	58	0	59	55·46	+0·19	9·5253	81	44	51·5	−3·7	0·8114	R.	B.	(*o*)
4	9	11	3	6	2	36	0	58	31·13	+0·20	9·5514	81	47	19·5	−3·8	0·8201	R.		(*p*)
7	8	20	13	5	23	26	0	54	44·36	+0·19	9·5293	81	53	23·2	−3·7	0·8129	R.	H.B.	(*q*)
9	7	1	28	4	12	21	0	52	24·89	+0·16	9·4486	81	56	37·5	−3·5	0·7999	R.	H.B.	(*r*)
11	7	49	49	5	8	43	0	50	6·75	+0·18	9·5207	81	59	28·7	−3·6	0·8112	R.	H.B.	(*s*)

Observers.—A.R., Dr. Rambaut; G.R., Mr. Gerrard Rambaut; W., Mr. W. Wickham; R., Mr. W. H. Robinson; H.B., Mr. H. G. S. Barrett; B., Mr. J. G. Balk.

In the computation of the parallaxes the adopted value of the Sun's mean horizontal parallax is 8″·80, and the geocentric distances, Δ, are taken from the *Astronomische Nachrichten*, Nos. 4359 and 4379.

The particular stars used in the reductions are given below under the heading "Authority for Co-ordinates of Comparison Stars."

Authority for Co-ordinates of Comparison Stars.

(*a*)	*Astrographic Catalogue*,	Bordeaux,	Tome	II.,	Cliché	777,	Nos.	76, 78, 83, 89, 93.
(*b*)	,,	,,	,,	I.,	,,	556,	,,	246, 250, 253, 270, 280, 283.
(*c*)	,,	,,	,,	I.,	,,	554,	,,	201, 213, 221, 227, 240, 267.
(*d*)	,,	,,	,,	II.,	,,	905,	,,	31, 34, 44, 52, 53, 58.
(*e*)	,,	,,	,,	I.,	,,	553,	,,	132, 133, 137, 140, 149.
(*f*)	,,	,,	,,	II.,	,,	776,	,,	7, 11, 15, 26, 35, 36.
(*g*)	,,	,,	,,	II.,	,,	775,	,,	38, 39, 40, 42, 43.
(*i*)(*j*)	,,	Toulouse,	,,	VII.,	,,	18,	,,	34, 42, 45, 51, 61, 70.
(*k*)	,,	,,	,,	VII.,	,,	14,	,,	81, 82, 84, 89, 92, 102.
(*l*)	,,	,,	,,	II.,	,,	13,	,,	29, 32, 34, 38, 40, 41.
(*m*)	,,	,,	,,	II.,	,,	11,	,,	24, 27, 28, 53, 54, 59.
(*n*)	,,	,,	,,	II.,	,,	8,	,,	67, 68, 70, 72, 74, 75.
(*o*)	,,	,,	,,	II.,	,,	8,	,,	59, 63, 66, 68, 70, 72.
(*p*)	,,	,,	,,	II.,	,,	8,	,,	54, 59, 60, 63, 66, 67.
(*q*)	,,	,,	{ ,,	IV.,	,,	7,	,,	50, 59, 60.
			{ ,,	II.,	,,	7,	,,	67, 68, 71.
(*r*)	,,	,,	,,	IV.,	,,	7,	,,	22, 24, 29, 34, 35, 41.
(*s*)	,,	,,	,,	IV.,	,,	7,	,,	3, 8, 14, 15, 22, 24.

Assumed Places of Comparison Stars for Observations on Dec. 18.

	Mean R.A. 1909·0.			Reduction to Appar. R.A.	Mean N.P.D. 1909·0.			Reduction to Appar. N.P.D.	Authority.
	h	m	s	s	°	′	″	″	
(*h*)	3	10	16·26	+3·21	76	2	1·4	−14·7	Leipzig I. (A.G.), 974.
	3	11	23·61	+3·21	76	29	3·8	−14·6	,, ,, 976.
	3	11	43·02	+3·22	75	47	28·7	−14·7	Küstner, 1900, 1380.
	3	12	16·87	+3·21	76	27	34·7	−14·6	Leipzig I. (A.G.), 980.
	3	12	50·62	+3·22	76	29	10·4	−14·5	,, ,, 981.
	3	14	52·75	+3·22	76	30	2·1	−14·4	,, ,, 990.

In two cases a departure had to be made from the method of reduction just described. In the first of these, viz. December 18, no astrographic catalogue was available covering the region in which the comet lay. In this case the measures were compared with standard co-ordinates computed for the six stars whose spherical co-ordinates are given above under the heading "Assumed

Places of Comparison Stars for Observations on Dec. 18." The second exceptional case was that of February 7, when three of the comparison stars had to be taken from one of the Toulouse zones and three from another. In this case the R.A. and Decl. of each of the stars were deduced from the Toulouse rectangular co-ordinates, and standard co-ordinates, referred to a convenient centre, were computed for comparison with the Oxford measures.

Observers' Remarks.

1909 Nov. 5. Search was made by W. with the 18-inch telescope for Halley's Comet, and it was soon discovered with power 290 as a faint luminous haze. B. also saw it definitely. Eventually Dr. R. and H. B. also viewed the object, when its motion amongst the stars was evident. An observation for position, from circle readings only, gave the following result: G.M.T. $12^h\ 9^m\ 49^s$: Local Sidereal $3^h\ 3^m\ 4^s$: Apparent R.A. $5^h\ 44^m\ 8^s$: Apparent N.P.D. $73^\circ\ 9'$.

Nov. 17. The comet appears dull, with a central nucleus occasionally brightening up. Suspect an elongation, P.A. 135°. The comet is easily seen in the field of the 7-inch telescope with power 90. Conjunction of faint star with comet observed at $5^h\ 5^m\ 12^s$ Local Sidereal: star very slightly south.

Nov. 18. Nebulous haze, 12″ in diameter. Nucleus precedes centre and is south.

Nov. 22. Conjunction of a 10 mag. star with comet at $3^h\ 42^m\ 10^s$ Local Sidereal, and at about 2′ north.

Nov. 23. Comet about 20″ diameter: condensation diffused. Bright moonlight.

Dec. 4. Nucleus 10·5 mag. Nebulosity traced for 25″ or slightly more. Short tail suspected, P.A. 135°.

Dec. 18. Nucleus 11 mag.

Dec. 31. Mag. 11·5. Diameter of nebulosity about 30″. Comet just visible in the 3-inch finder, power 23.

1910 Jan. 10. Nucleus seen intermittently only. Magnitude 11·5. The photographic image was found to be faint, ill-defined, and difficult to measure. The place given is deduced from the mean of measures made by four observers.

Jan. 12. Magnitude of condensation, 12. Conjunction of a 10 mag. star at $2^h\ 18^m\ 6^s$ Local Sidereal, and 45″ north.

Jan. 19. Condensation, magnitude $11\frac{1}{2}$. Moonlit sky.

Feb. 2. Magnitude of nucleus $10\frac{1}{2}$ or 11, stellar at times. Coma 40″ in diameter.
Feb. 3. Mag. 11. Sky slightly hazy.
Feb. 4. Image diffused.
Feb. 7. Mag. 10.
Feb. 11. Mag. 10 or $10\frac{1}{2}$. Faint elongation, P.A. 85°.

Radcliffe Observatory, Oxford:
1910 *April* 13.

Observations of Comet b 1909, *from photographs taken with the 30-inch Reflector of the Thompson Equatorial at the Royal Observatory, Greenwich, in the year* 1909.

(*Communicated by the Astronomer Royal.*)

The following positions were obtained from photographs taken with the 30-inch reflector at the Royal Observatory, Greenwich. They are referred to the equator and equinox of 1909·0, and are corrected for the part of the aberration arising from the Earth's motion. They are not corrected for parallax, or for the part of the aberration arising from the comet's motion.

The true positions for 1909·0 may be obtained by applying the corrections for parallax and Earth's aberration and antedating for the light-time.

The plates were measured with the astrographic micrometer. Six reference stars were, as a rule, measured with the comet, their positions being derived from the catalogues of the Astronomische Gesellschaft.

Log Parallax Correction = log Parallax Factor − log Δ.

Date and G.M.T. 1909.	R.A. 1909·0.	Log Parallax Factor.	Dec. 1909·0.	Log. Parallax Factor.	Corr. for Earth's Aberrn. R.A.	Corr. for Earth's Aberrn. Dec.
d h m s	h m s		° ′ ″		s	″
Aug. 14 13 6 42	0 21 22·03	−9·297	+36 35 11·4	+0·408	+1·11	−3·2
16 13 5 45	0 25 31·71	9·294	37 32 13·5	0·382	1·15	3·2
18 12 27 55	0 29 47·01	9·415	38 28 47·6	0·402	1·17	3·2
19 12 40 25	0 32 0·97	9·375	38 57 46·1	0·370	1·19	3·2
28 10 44 29	0 53 54·79	9·618	43 13 41·0	0·459	1·33	3·1
28 11 12 25	0 53 57·72	9·577	43 14 13·9	0·400	1·35	3·1
Sept. 6 9 55 7	1 21 12·41	9·695	47 22 25·7	0·479	1·46	3·3
8 10 7 39	1 28 16·60	9·689	48 15 16·7	0·429	1·50	3·4
11 11 17 55	1 39 47·82	9·603	49 32 17·3	0·178	1·54	3·5
14 9 59 48	1 51 56·18	9·718	50 41 53·6	0·403	1·58	3·7
14 13 58 39	1 52 38·04	−8·703	+50 45 42·5	+8·985	+1·58	−3·8

Royal Observatory, Greenwich:
1910 *April* 4.

Observations of Saturn's Ninth Satellite, Phœbe, *from photographs taken with the 30-inch Reflector at the Royal Observatory, Greenwich, in the year* 1909.

(*Communicated by the Astronomer Royal.*)

Photographs of Phœbe have been taken with the 30-inch reflector during the recent opposition of Saturn, on every possible occasion. In all 12 photographs have been secured on 9 nights, between 1909 October 5 and 1910 January 10.

The position of the satellite has been measured on photographs taken with the reflector with reference to faint comparison stars (of eleventh or twelfth magnitude), symmetrically distributed about the satellite. The positions of these faint comparison stars were then measured relatively to the reference stars (of eighth to ninth magnitude) on photographs (with exposures of 40^m and 30^m) taken with the astrographic 13-inch refractor. The field, sensibly free from distortion, being much larger with this telescope than with the reflector, about 20 reference stars were available on the plates. As Saturn moved slowly, it was possible to make one reference plate serve for several photographs, which were each referred to it. The constants were determined in the usual manner, all the stars on the plate given in the Astronomische Gesellschaft catalogues being used for this purpose. Right Ascensions and Declinations of the satellite were then determined, and compared with the corrected tabular places of Saturn after applying the corrections

$$\text{in R.A.} + 0^s{\cdot}10 \quad \text{and} \quad \text{Dec.} + 0''{\cdot}7$$

as determined below.

The G.M.T. is the arithmetical mean of the times of beginning and end of exposure.

Observations of Phœbe.

Date and G.M.T.			Exp.	Apparent R.A.			Apparent Dec.			Phœbe − Saturn.			
										R.A.		Dec.	
1909.	d	h m	mins.	h	m	s	°	′	″	m	s	′	″
Oct.	5	11 51·2	40	1	21	10·40	+5	35	43·6	+1	42·17	+12	29·2
	5	12 38·0	40	1	21	9·73	5	35	39·5	1	42·06	12	28·6
	6	12 39·3	40	1	20	53·38	5	34	0·0	1	43·14	12	37·3
	8	12 25·1	50	1	20	20·27	5	30	37·9	1	44·91	12	50·7
	21	11 1·7	90	1	16	42·24	5	9	4·2	1	55·46	14	16·0
	21	12 58·4	85	1	16	41·01	5	8	58·0	1	55·64	14	18·1
Nov.	5	10 0·2	90	1	12	44·29	4	46	44·5	2	5·17	15	38·3
	5	11 30·5	75	1	12	43·21	4	46	36·1	2	5·05	15	35·2
	30	8 15·4	40	1	7	56·06	4	22	42·4	2	14·86	16	57·1
Dec.	3	6 50·2	55	1	7	34·97	4	21	20·7	2	15·49	17	2·8
1910.													
Jan.	3	7 45·0	90	1	7	15·68	4	28	29·9	2	16·29	17	9·5
	10	7 26·8	80	1	8	3·63	+4	35	26·2	+2	15·07	+16	57·5

Errors of Tabular Place of Saturn.

The positions of the satellite given above depend on the positions of certain stars taken from the catalogues of the Astronomische Gesellschaft, and will be affected by the mean error in the places of these stars. To eliminate this it is necessary to determine the position of Saturn referred to the same stars.

For this purpose a number of photographs of Saturn were taken with the 26-inch refractor, using the occulting shutter. By this means good measurable images of Saturn were obtained, together with sufficiently exposed images of the reference stars. The field of the 26-inch on a 16 c.m. plate is one square degree, and the reference stars in this area were measured together with Saturn.

The adopted places of these stars were deduced from measures made on the astrographic reference plate, derived from all the available stars in the Astronomische Gesellschaft catalogues. The places of these reference stars, and therefore the deduced place of Saturn, will be affected by the mean systematic error of all the catalogue stars on the reference plate, and will thus be comparable with the deduced places of the satellite.

Four photographs were selected for measurement. Four images of Saturn and of each of the stars were measured on each plate in the astrographic micrometer, and the following are the results obtained:—

Errors of N.A. Tabular Place of Saturn.

	Tab. − Obs.	
	s	″
Oct. 25	−0·11	−0·6
25	− ·10	−1·0
Nov. 5	− ·09	−0·8
5	− ·09	−0·5
Mean	−0·098	−0·73

Corrections for these mean errors have been applied to the tabular places of Saturn as already stated.

Notes.

Oct. 8. Very faint.
Dec. 3. Very faint and ill-defined.

Royal Observatory, Greenwich:
1910 *April* 4.

On Short-Period Terms in Latitude Drifts in Sun-spots. Papers of the I.U.S.R. Computing Bureau, No. VI.

By F. J. M. Stratton, M.A.

The fifth of this series of papers (*M.N.*, vol. lxix., No. 9) concludes with a short account of an attempt to discover traces of some short-period term which might explain some of the puzzling phenomena of latitude drift in sun-spots. It is there stated that the analysis of years 1892–5 round a sun-spot maximum, while indicating the presence of possible periods, showed no short period of marked intensity. A further study of the years of maximum 1881–4 confirms the former suggestion that the periods indicated as present were not real periods. At any rate little agreement is shown between the figures resulting from the separate analyses.

The method adopted in the second investigation was, as before, Dr. Schuster's periodogram. The discordance between the results given by the two intervals is well shown by the figures of the primary analysis for periods of 12, 15, 18, 21, 24, 27, 30, 33, 36, 39 days. The following table gives for each period the value of $(A^2 + B^2)/(A_0^2 + B_0^2)m$, the ratio of the intensity of the "bright line" (corresponding to the period) to the mean "brightness of the spectrum."

Table I.

Period in Days.	Brightness.	
	1881–4.	1892–5.
12	0·30	0·83
15	0·35	1·70
18	0·82	2·61
21	1·90	0·45
24	2·95	0·55
27	1·41	0·23
30	0·55	3·55
33	3·52	0·94
36	1·10	5·55
39	0·43	1·62

The disagreement could hardly be more complete. This does not, of course, imply that the method is at fault; but it confirms the suggestion that the periods indicated in the earlier paper were not bright enough to be looked upon as real. They were within the limits which practice and theory alike assign to the working of accidental error.

The secondary analysis in the earlier paper was made by a search between the periods of 13·6 days to 43·3 days at successive

intervals of about 0·03 of a day. To be more exact, the successive periods T′ examined are given by the equation

$$\pm nT' = 5 \times 180\,(T - T') \quad . \quad . \quad . \quad (1)$$

where T is the primary period used for the search in its own immediate neighbourhood, and n takes the values 1 – 90. The coefficient 5 on the right-hand side occurs because in the primary analysis 5 periods were always taken together as a basis for the analysis. Now the periods suggested by the secondary analysis of of the 1892–1895 period are as follows:*—

Table II.

Primary Period.	Secondary Period.	Amplitude.	Primary Period.	Secondary Period.	Amplitude.
d	d		d	d	
15	15·98 or 14·14	20·0	24	24·41 or 23·61	18·7
15	16·24 or 13·93	27·0	24	25·76 or 22·46	21·4
15	16·46 or 13·78	19·9	27	28·26 or 25·85	26·7
18	18	24·0	27	30·0 or 24·55	35·05
18	19·42 or 16·65	22·3	30	30·0	7·1
21	21·75 or 20·30	18·4	33	35·15 or 31·10	10·7
21	22·26 or 19·87	12·6	36	36·0	9·0
21	22·85 or 19·55	12·5	39	39·75 or 38·28	15·7

The ambiguity arises from the fact that the secondary analysis does not distinguish immediately between periods on opposite sides of the primary. It does not take notice of the doubtful sign of equation (1) above. The two periods can be examined independently afterwards and the correct one distinguished. This has not been done in the above case for two reasons. The mean intensity of the periodogram is only less than $\frac{1}{5}$ that of any period in one case, where the amplitude is 35·05. In this case the periods indicated are so far removed from the primary suggesting them that if they were real they should be clearly indicated in the

* The figures given in the former paper 27·68 d and 33·92 d are in error owing to a numerical blunder.

analyses of the adjacent primary periods. As this is not the case, the period is presumably accidental.

The secondary analysis of the period 1881–4 was not carried through in the same complete manner as in the previous work. The method adopted was the graphical one described by Dr. Schuster in the Stokes Commemoration volume of the *Cambridge Philosophical Transactions* (vol. xviii.). This method has the advantage over the numerical one that it removes the ambiguity with regard to any period indicated. It does not, however, give the amplitude of the period in the first instance. As, however, all we are looking for is agreement between the two sun-spot maxima, all we require at first is the complete set of periods suggested by graphical examination of the primary analysis. These were as follows:— 14·16, 14·34, 15·57, 16·82, 17·63, 18·44, 20·66, 21·53, 23·05, 25·01, 25·92, 27·23, 27·70, 31·56, 32·32, 32·77, 34·91, 37·58, 38·25, 39·80, and 40·40 days.

This is the complete set of periods which could be twisted out of the graphs, and it was made as complete as possible so that no coincidence with the earlier work might be missed. Only four periods agreed at all closely in the two lists.

Table III.

	d	d	d	d
1881–4	14·16	25·92	38·25	39·80
1892–5	14·14	25·85	38·28	39·75

It remained to determine whether these periods would in the interval 1881–4 show sufficient intensity to justify any claim being put forward for their genuineness. By a slight modification of the figures of the primary analysis it was easy to determine for these few given periods their relative intensities as shown by the quantity mentioned above $\frac{A^2 + B^2}{m(A_0^2 + B_0^2)}$. The values obtained were as follows:

Table IV.

Period.	Brightness.
d	
14·16	1·44
25·92	2·62
38·25	4·30
39·80	3·40

Of these periods, then, there is not one in the 1881–4 period nor in the 1892–5 period which falls outside the limits assigned to accidental errors. Further investigation has therefore not led to the determination of any real short-period terms in the latitude drift of sun-spots between 14 and 40 days period.

On Magnitude Equation in Long-Exposure Photographs.

By F. J. M. Stratton, M.A.

In discussing a magnitude effect which was displayed in some long-exposure photographs of the Pleiades (*Memoirs of the R.A.S.*, vol. lvii. p. 166) the author suggested that the effect might be due to the distortion of the images caused by differential refraction. A detailed examination of this hypothesis fails to confirm the suggestion. Dr. A. A. Rambaut has discussed the question of the distortion of photographic star images due to refraction (*Scientific Proceedings of the Royal Dublin Society*, vol. viii. (N.S.) p. 186), and has shown that the amount by which a star image is disturbed relative to the guiding star may be put in the following form,

$$\text{The distortion in } x = \alpha X + \beta Y$$
$$y = \delta X + \epsilon Y,$$

where α, β, δ, ϵ depend on the latitude of the observatory, the declination of the guiding star, and the hour angles of the commencement and end of the exposure. X, Y are the ordinary rectangular coordinates of the distorted star relative to the guiding star. Dr. Rambaut has further given tables from which one may compute the values of α, β, δ, ϵ for any photograph taken in the latitude of Dunsink Observatory. Assuming that these tables are sufficiently accurate for use in the case of photographs taken at Greenwich and Oxford, and that 20° N. is near enough to the declination of Alcyone (23° 46′·5 N.) to give approximate results, the values of α, β, δ, ϵ were calculated for the three plates which showed the magnitude effect mentioned above. The values found were—

Plate.	α.	β.	δ.	ϵ.
Greenwich 738	0·000007	0·00005	0·00004	0·000007
Greenwich 755	0·00006	0·00021	0·00020	0·00007
Oxford 24	0·00016	0·00023	0·00028	0·00023

Now if this distortion has equal effect in displacing the apparent centres of stars of all magnitudes, bright and faint alike, then it will be fully allowed for in the process of reducing one plate to the other. But if—and this is the assumption provisionally adopted—the effect of the distortion is different for stars of different magnitudes, then this effect will remain even after the reduction, and we shall find a magnitude drift on one plate relative to the other. There are two ways in which differences of magnitude between stars might affect the displacement of star-centres arising from distortion. Either the irregular fringe of the star image due to distortion may only be visible in the brighter images, and may produce an apparent shift of the bright images only, or else it may be present in all the images, but, owing to the more decided difference between

the fringe and core of a bright image than of a faint one, may be allowed for by the eye in measuring the centre of a bright image, while such allowance may be impossible in the fainter images. In this case the faint images would be displaced. An opportunity of testing these rival hypotheses seemed to lie in the examination of the magnitude drift in the Pleiades photographs.

Some particulars with regard to the three photographs mentioned above are here repeated from the former paper.

Observatory.	Plate No.	Date.	Exposure.	Centre of Exposure.
Oxford University	24	1891 Feb. 11	120	180 min. after transit.
Greenwich	738	1893 Jan. 24	39	26 ,, ,, ,,
,,	755	1893 Feb. 7	180	73 ,, ,, ,,

The two photographs O. 24 and G. 755 were both reduced to G. 738 as standard, a carefully selected group of stars being chosen from the three brightest classes of stars to serve as standard stars in the reduction. A carefully chosen group of 118 stars was examined on each plate, this group containing about 17 stars of each magnitude class, distributed as evenly as possible over the plate. Further, all the stars considered lay in a circle of 35′ radius round the centre of the plate. Each of the plates O. 24 and G. 755 when reduced to G. 738 showed a marked magnitude equation, the sign of which was different in the two cases. Also these magnitude drifts were very unevenly distributed over the plate in both cases, and it was this uneven distribution which seemed to call for an explanation.

As a first step towards testing whether differential refraction could explain the phenomenon, the 118 stars were divided into two groups. The four brightest classes, containing 59 stars, formed the one group, the three faintest classes formed the other. One of these groups—the brighter one, containing all the standard stars of the reduction—showed practically no magnitude drift; the fainter group showed a decided drift. It was assumed that one group had suffered from distortion, and consequent displacement of star-centres, while the other group had not. Which group, if either, had been displaced, according to Dr. Rambaut's formulæ, could be shown as follows. Assume for the moment that the bright stars suffered distortion so that the values found above for α, β, δ, ϵ apply to the bright stars. Then in the coefficients a, b, d, e of the reduction,

$$X = x + ax + by + c \qquad Y = y + dx + ey + f,$$

by which the plates are brought to standard positions, there are included terms

α (standard plate) $-$ α (reduced plate)

β (standard plate) $-$ β (reduced plate), etc.

Since the faint stars are by hypothesis not distorted, this part of a, b, d, e should not be present in the reduction for the faint stars. It may be taken out again by a further reduction of the faint stars according to the formulæ—

$$\xi = X + a'X + b'Y + c' \qquad y = Y + d'X + e'Y + f'$$

where

$$a' = \alpha(\text{reduced plate}) - \alpha(\text{standard plate})$$
$$b' = \beta(\text{ ,, ,, }) - \beta(\text{ ,, ,, })$$
$$d' = \delta(\text{ ,, ,, }) - \delta(\text{ ,, ,, })$$
$$e' = \epsilon(\text{ ,, ,, }) - \epsilon(\text{ ,, ,, })$$

The smallness of the coefficients concerned makes it indifferent whether we employ X, Y or x, y in the product terms in the right-hand side of the above equations.

Thus, according to our assumptions, the coefficients for the further reduction of the faint stars (already once reduced to G. 738 by means of standard bright stars), when the faint stars of the standard plate are used as standard, should be as follows :—

	a'.	b'.	d'.	e'.
G. 755	+0·00005	+0·00016	+0·00016	+0·00006
O. 24	+0·00015	+0·00018	+0·00024	+0·00022

Also if the faint stars and not the bright ones are displaced by distortion, these coefficients should all be of the opposite sign. One more point should be noted: since it is almost certain that either of these hypotheses is an exaggeration of what may be the true state of the case, that all the stars are affected, but to an extent depending on the magnitude, we should expect to find as a matter of fact coefficients somewhat smaller appearing in our results. Not much importance need be attached in the case of G. 755 to a', e', which are both small, but something may be learnt from the sign and size of b', d' obtained from the photographs.

Now let us turn to our actual results and compare them with the theoretical. A second reduction of the fainter stars on G. 755 and O. 24 to the faint stars of G. 738 as standards gives

	a'.	b'.	d'.	e'.
G. 755	−0·00002	+0·00008	+0·00011	+0·00004
O. 24	+0·00002	−0·00012	−0·00006	+0·00008

The first point that strikes the eye in examining these figures is the fact that the two important coefficients b', d' are of opposite sign in the two cases. For G. 755 the agreement with theory is not bad, the values found being at any rate of the right order of magnitude and, except for the smallest coefficient, of the right sign. While it may yet be possible to account for the difference of the two sets of results by suggesting that on one plate the images are of such a nature that the fainter images are displaced by distortion,

and on the other the brighter images, such an explanation can neither be satisfactory nor final. The problem set up by the unequal distribution of the magnitude drift in different parts of the plate remains unsolved, except for those who are willing to regard it as accidental. The practical disappearance of the magnitude drift in the more modern photographs of 1906, 1907 may help towards the acceptance of this second suggestion. But a fresh examination of the residuals leaves in the writer's mind a strong impression that the uneven distribution of the residuals represents some real acting cause. In the hopes that an explanation may be suggested by some other investigator, he repeats the table of residuals from the former paper (p. 167) :—

The plates were divided by the diagonals into four sections, and the mean residuals in x, y for the brighter and fainter stars in each section are given below.

	Section I.	Section II.	Section III.	Section IV.
Brighter Stars	$x\,(-)^m$	$y\,(+)^m$	$x\,(+)^m$	$y(-)^m$
Number of stars	13	14	15	17
Reduction.		*Mean residuals in x.*		
G. 755 to G. 738	− 0·7	− 1·7	+ 2·5	0 0
O. 24 to G. 738	− 1·2	− 1·8	− 0·3	− 2·4
		Mean residuals in y.		
G. 755 to G. 738	− 1·2	+ 1·4	− 2·4	+ 0·8
O. 24 to G. 738	+ 0·8	+ 4·2	− 4·3	− 2·2
Fainter Stars.				
Number of stars	11	13	23	12
Reduction.		*Mean residuals in x.*		
G. 755 to G. 738	+10·0	+11·1	+ 4·9	+ 1·8
O. 24 to G. 738	− 9·4	−12·3	−15·3	−10·9
		Mean residuals in y.		
G. 755 to G. 738	− 5·5	+ 2·8	+ 2·6	− 2·7
O. 24 to G. 738	− 1·5	+ 0·2	− 6·1	− 2·7

On the Determination of Cœlostat Errors.

By E. B. H. Wade, M.A., and H. E. Hurst, M.A., B.Sc.

(*Communicated by Professor H. H. Turner.*)

§ 1. Introduction.—Professor Turner has already* described the method of determining the errors of a cœlostat by attaching a theodolite to the polar axis, and reading the apparent declinations of stars. By this means we can determine the errors of the mounting in level and azimuth, but not the parallelism of the mirror to the axis. For this latter purpose he either reverses the mirror in its bearings or else follows a star for a sufficient length of time to infer the want of parallelism from the movement of the image in declination. The cœlostat which we employ cannot be tested in the way described by Professor Turner, first because it does not admit of the attachment of a theodolite, and secondly because the mirror is not reversible. These shortcomings are more than made up for by the simplicity of design which results, and we have devised new methods of determining the cœlostat errors which may be useful to those who adopt a similar construction.

§ 2. Authors' First Method.—The easiest way to understand the method we employ is to remember that a cœlostat in perfect adjustment is equivalent to a mercury pool on the terrestrial equator, and the means which we use are the same as those suitable for proving that a mercury pool is on the equator. Now the traveller who wishes to establish this fact observes the maximum or meridian double-altitude of a star. If he is on the equator this double-altitude is twice the star's polar distance, and, similarly, if with the sextant we observe the angle between a bright star and its image in the cœlostat mirror, this angle attains a maximum value of twice the polar distance if the cœlostat is in perfect adjustment. If the cœlostat is out of adjustment so that its normal meets the celestial sphere in a declination Δ, the maximum angle observed is $2(p-\Delta)$, where p is the star's polar distance. Of course the observation of a maximum angle with a sextant is a somewhat tedious process, but we can easily avoid the strain if we elect to observe only at the time of theoretical maximum, for which purpose a watch giving sidereal time to within about one minute is needed. The cœlostat should also be fitted with a rough hour circle. The index of this circle can be made to read 0^h when the cœlostat normal is on the meridian, as follows:—The cœlostat is rotated till the mirror comes into a nearly vertical plane. An Abney's level, reading zero, is pointed at it, and the slow motion of the cœlostat is turned until the image of the Abney level is sighted on its own cross thread. The mirror is then vertical, and the index should be made to read 6^h, after which it will give correct

* *M.N.*, vol. lvi. p. 408.

hour angles. Let us suppose that we wish to make an observation with α Lyræ at an hour angle of $+3^h$. The right ascension of the star is $18^h\ 33^m$. The cœlostat hour circle is set to $+3^h$, and the observation is made at local sidereal time $21^h\ 33^m$. The observed angle will then be a maximum.

§ 3. Details of Procedure.—At least three stars must be selected for observation, one near the meridian and the other two at distances of at least three hours east and west respectively. The hour circle is set to the correct hour angle, the sextant is clamped at a reading equal to twice the polar distance, and the telescope is pointed at the reflection of the star. The sextant is then slowly rotated round the optic axis in the usual way, and the doubly-reflected star image will be seen entering the field, and at the appointed time the two images are brought to contact. Usually three contacts are observed for each star at intervals of ten minutes, the hour circle being of course moved on ten minutes each time.

§ 4. Calculation of Constants.—It is evident that if we can obtain the value of Δ at at least three points in the track which the cœlostat normal sweeps out as it travels from the east horizon to the west, we can determine the constants of the instrument. For let m and n be the rectangular co-ordinates of the pole of the cœlostat and let γ be the error of parallelism; then evidently $\Delta = m \sin t + n \cos t + \gamma$, and three equations of this form will determine m, n, and γ. It should be remembered that the apparent polar distance of stars is affected by refraction, and the measured distance by errors of graduation of the sextant, and for accurate work these must be allowed for. The former correction is found from the usual formulæ, and the latter is usually found from the certificate of comparison of the sextant. Where none is provided, the sextant can be calibrated by measuring the distances between pairs of bright stars and comparing it with theory.

§ 5. The Observations.—In our observations the refraction is allowed for in each observation, and the sextant (an 8-inch by Troughton & Simms) having no certificate, was calibrated by observing a large number of star-distances. The table which follows gives the results of our observations and also the differences between the experimental values of the difference Δ, and the values computed from the formula $\Delta = m \sin t + n \cos t + \gamma$, where $m = 6'45''$, $n = 16'36''$, and $\gamma = -5'24''$, which numbers were found from the least square solution of the observation equations.

§ 6. Authors' Second Method.—In this method a theodolite with a vertical circle is mounted so that when its telescope is in the meridian it can be pointed at the mirror of the cœlostat. In order that the telescope may move over a wide range while pointing at the mirror, the theodolite is placed as near as possible to the cœlostat.

Now if the cœlostat is accurately adjusted, both it and the telescope can be set so that the light from a star within a certain range of declination is reflected by the mirror along the telescope.

TABLE I.

Giving Results of Sextant Observations on Cœlostat Errors.

Star.	Observed North Polar Distance.	Correction for Refraction and Sextant Error.	Corrected North Polar Distance (Mean).	Ephemeris North Polar Distance.	Difference.	Hour Angle.	Mean Hour Angle.	Residual on Difference.
	51° 27′ 58″	− 9″ − 15″				− 0h 33m		
α Lyræ . .	28 43	= − 24″	51° 28′ 04″	51° 17′ 46″	+ 10′ 18″	− 0 23	− 0h 23m	+ 8″
	28 43					− 0 13	− 5° 45′	
	70° 26′ 42″	+ 47″ − 30″				+ 4 29		
Arcturus . .	27 12	= + 17″	70° 26′ 59″	70° 20′ 27″	+ 6′ 32″	+ 4 39	+ 4h 39m	+ 9″
	26 12					+ 4 49	+ 69° 45′	
	61° 21′ 15″	+ 20″ − 25″				− 4 04		
α Andromedæ	22 48	= − 5″	61° 22′ 15″	61° 24′ 55″	− 2′ 40″	− 3 54	− 3h 54m	+ 11″
	22 58					− 3 44	− 58° 30′	
	54° 46′ 37″	+ 20″ − 0″				− 4 34		
β Andromedæ	47 02	= 20″	54° 47′ 26″	54° 51′ 57″	− 4′ 31″	− 4 24	− 4h 24m	− 18″
	48 38					− 4 14	− 66° 0′	
	38° 41′ 12″	− 10″ − 10″				+ 3 06		
γ Draconis .	41 17	= − 20″	38° 40′ 32″	38° 29 41″	+ 10′ 51″	+ 3 16	+ 3h 16m	− 15″
	40 07					+ 3 26	+ 49° 0′	

This can still be done if the adjustment of the cœlostat is not perfect, and from the observed dip of the telescope, and the known declination and hour angle of the star, the departure of the cœlostat normal from the celestial equator can be determined.

We shall now give a short account of the method employed and the theory upon which it is based.

§ 7. Details of Procedure:—

1. The theodolite is mounted to the south of the cœlostat (in the northern hemisphere), and then, by means of a setting on a distant mark whose azimuth is known, the telescope is brought approximately into the meridian.

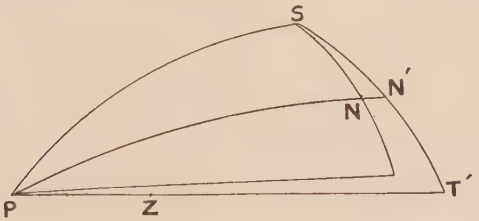
2. The zero of the vertical circle is then determined by a setting on a star at culmination.

3. If the approximate sidereal time is not known, it can be found from direct observation of a star's altitude.

4. A star is selected within the proper range of declination. The cœlostat mirror is then turned so that its normal moves out from the meridian towards the star through half the hour angle of the star. This can be done by means of the hour circle mentioned in the previous method.

The star can now be sighted by setting the telescope to the theoretical dip, when it should be in or near the field of view. The telescope is then set by moving it in the meridian until the image of the star travels along the horizontal crosswire. The sidereal time and the reading of the vertical circle are observed. If this is done for stars with hour angles about 0 and $+4$ and -4 hours, values of the constants giving the departure of the normal can be found, as shown in the preceding part of the paper.

The following is a *résumé* of the theory of the method. The diagram is a projection on a sphere from a centre which is a point on the cœlostat mirror where a ray from the star is reflected along the axis of the telescope.



P is the pole, Z the zenith, T the axis of the telescope, N the normal to the cœlostat mirror, S the star, N′ and T′ are the positions of the normal and telescope when the cœlostat is adjusted correctly, *i.e.* N′ is on the equator of the sphere.

Z T′ is the complement of the theoretical dip of the telescope. Hence P T′ − P T is approximately the difference between the calculated and observed dip. We shall call this d. N N′ is

the departure of the cœlostat normal from the equator, which we shall call Δ.

It can be shown that $PT' = 180° - PS$
$= 90° +$ declination of S

and that $SPN' = N'PT' = \frac{1}{2}t$ where t is the hour angle of S.

By solving the triangles S P N, N P T, and using the above relations, we find to the first order of small quantities

$$\Delta = \tfrac{1}{2}d \sec \frac{t}{2}.$$

The theoretical dip, d, can be found as follows:

$PT' = 90° +$ Decl. of $S = 90° + \delta$
$PZ = 90° -$ Latitude of place of observation
$= 90° - \phi$.

Hence $d = 90° - ZT' = 90° - (PT' - PZ)$
$= 90° - (\phi + \delta)$.

From this the telescope can be set to find the star, and the range of declination within which stars can be observed can also be found.

The following example will explain the method:—

TABLE II.

Star's Name.	β Cassiopeiæ.	η Draconis.	α Ursæ Majoris.
	h m s	h m s	h m s
Star's hour angle $= 2t$	0 18 52	8 35 56	−8 13 24
Star's true declination $= \delta$	58° 39′·0	61° 43′·1	62° 14′·3
Star's apparent declination $= \delta'$	58 38·4	61 43·0	62 14·9
Theodolite reading	92 21·0	88 55·0	88 06·0
Same corrected $= \zeta'$	92 02·3	88 36·3	87 47·3
$180 - (\phi + \delta')$	91 31·1	88 26·5	87 54·6
$\zeta' - \{180 - (\phi + \delta')\} = d$	31·2	09·8	07·4
	h m s	h m s	h m s
Hour angle of cœlostat $= t$	0 9 26	4 17 58	−4 6 57
$\Delta = \frac{1}{2}d \sec t =$	+15′·6	+11′·2	−7′·8

The zero correction − 18′·7 applicable to the readings of the theodolite was found from a pointing to γ Ursæ Minoris at inferior culmination.

From the observations given in the table, values of Δ are found, and from these the constants giving the deviation of the normal for any hour angle are found from the equation

$$\Delta = m \sin t + n \cos t + \gamma.$$

The values determined by the above experiment are

$$m = 11'·3 \quad n = 24'·8 \quad \gamma = -9'·6$$

As, in the interval between the observations by the authors' first and second methods, the cœlostat had been dismounted and taken to pieces, no significance attaches to the differences in the values of m, n, and γ given by the two solutions.

§ 8. Conclusion.—An examination of the residuals given for Δ in Table I. shows that the first method is a satisfactory one for determining the errors of a cœlostat, and that they can be found with more accuracy than is generally necessary. The observations present no difficulty to one accustomed to the use of the sextant. To those unfamiliar with this instrument, the registering of contacts often presents considerable difficulty, but when we consider how valuable an instrument is the sextant, capable of performing many of the duties of a small theodolite, at a fifth of the cost and the weight, facility in using it is a habit strongly to be encouraged.

The second method can be made as accurate as is required by the use of a good theodolite and the observation of several stars. The instrument used in the above determination was an old 5-inch tacheometer, from which great accuracy could not be expected.

Babbage's Analytical Engine. By Major-General H. P. Babbage. (Plate 15.)

Charles Babbage died in 1871. He commenced the Difference Engine about 1822, and the Government abandoned it in 1842. He commenced the Analytical Engine about 1833.

A few years before his death he began to execute in metal that part which he called the "Mill," where the operations of addition, subtraction, multiplication, and division can be performed.

I will give here an extract from Part II. of his *Essay towards the Calculus of Functions*, 1816, because it shows the working of his mind at that time, which further on led him to devote his life to the perfection of machinery for the numerical solution of Functions arrived at by mathematical analysis:—

"My subsequent inquiries have produced several new methods of solving functional equations containing only one variable quantity and much more complicated, and have convinced me of the importance of the Calculus, particularly as an instrument of discovery in the more difficult branches of analysis. Nor is it only in the recesses of this abstract science that its advantages will be felt: it is peculiarly adapted to the discovery of those laws of action by which one particle of matter attracts or repels another of the same or a different species; consequently it may be applied to every branch of natural philosophy, where the object is to discover by calculation from the results of experiment the laws which regulate the action of the ultimate particles of bodies. To the accomplishment of these desirable purposes, it must be confessed that it is in its present state unequal; but should the

labours of future inquirers give to it that perfection which other methods of investigation have attained, it is not too much to hope that its maturer age shall unveil the hidden laws which govern the phenomena of magnetic, electric, or even of chemical action."

To which I would add also the laws which govern our Cosmos, the leading object of this Society.

By his will he left all that existed of his analytical engine, its drawings and notations, as well as his workshop and tools, to me, his youngest son. I was at that time on furlough in England, and after his death I endeavoured to complete the work as far as the instructions in the hands of the workmen admitted, and in that state it remains in the South Kensington Museum at the present day.

I had to return to India at the end of my leave, but retired from the Indian Service in 1874.

Among the things which came to me in his will there was a large number of pieces fitted and ready for the difference engine; but many of the frame plates had been cut up and used by my father for experimental work. I thought to replace them and put together what existed. I began by having plates made to complete the framework as originally designed, and to put in their places the pieces, some completely finished and others less so. I also contrived a new driving gear which answered perfectly, but I found the expenses heavy and the utility doubtful, and about 1879, not knowing what to do with it, I sent the whole (excepting five or six small pieces sent to different places) to the melting-pot.

About that time I heard that Mr. Wilkinson, a nephew and successor of Clement, had broken up his workshop and melted up what remained there of the unfinished pieces of the difference engine. Had I known this in time I might have kept what I had, for I still hold to the opinion expressed in *Babbage's Calculating Engine*, published in 1889, that the calculating part of the difference engine might have been completed, at the time the Government gave it up, for, say, £500.

In 1856 I turned my attention to the machine of the Messrs. Schentz, and, with a view of instructing myself, I applied my father's system of Mechanical Notation to their machine. My father was very pleased with my work, and sent me to exhibit my diagrams at the meeting of the British Association at Glasgow. The diagrams are now in the South Kensington Museum, and I have employed the notation for the present machine, and have found it very useful.

Soon after my return to England I began to think that I might be able to complete the "Mill," not as part of the larger machine which my father proposed, but something which would be practically useful by itself in the hands of a skilled operator.

The iron top and bottom frame plates were cast in 1880, and the work was carried on, somewhat intermittently, until the 21st. of January 1888, when the machine produced a table from 1st. to 44th. multiples of π to twenty-nine places of figures, which could

have been prolonged indefinitely ; but the machinery did not work smoothly, and in the 32nd. multiple of π the carriage had failed and a figure had gone wrong. For a time I was discouraged, and in 1896 circumstances led me to discontinue the work, and I turned to other less expensive pursuits and offered the unfinished work of my father, with all the drawings and papers belonging to it, as well as my own imperfect work, to the South Kensington Museum, and the offer was accepted.

In 1906 my attention was accidentally attracted to my work. I saw what was amiss and the way to remedy it, with the result that it was sent to the factory of Mr. R. W. Munro at Tottenham, and, under my close supervision, it has been completed and the apparatus made to print the calculated results on paper, from which a zinc block has been made.

The printed calculations which follow are specimens of its work.*

Cheltenham :
1910 *April* 8.

* It will be seen that the "multiples of π" are really multiples of the first 29 digits of π.

```
00001  1000000000000000000000000000
                                  -1
       ----------------------------
00002  0999999999999999999999999999
                                  +1
       ----------------------------
00003  1000000000000000000000000000
```

MULTIPLES OF π.

```
00001  03141592653589783238462643383
00002  06283185307179566476925286766
00003  09424777960769349715387930149
00004  12566370614359132953850573532
00005  15707963267948916192313216915
00006  18849555921538699430775860298
00007  21991148575128482669238503681
00008  25133741228718265907701147064
00009  28275333882308049146163790447
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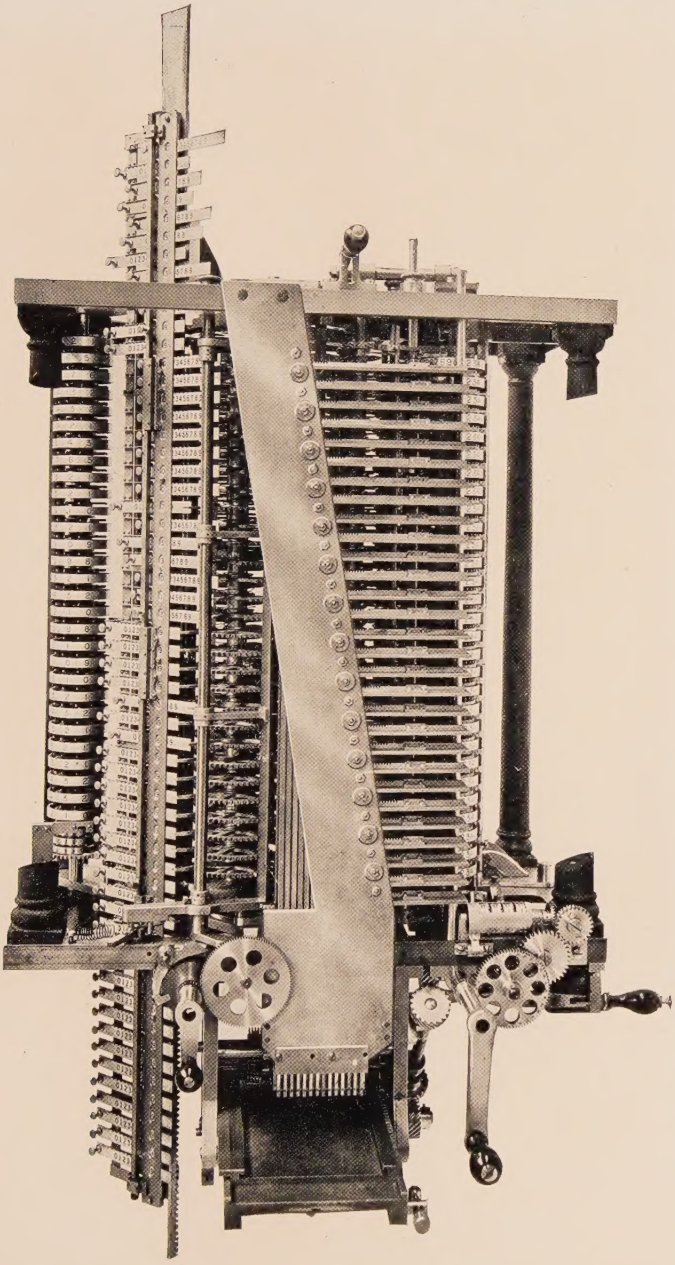
Specimen of work printed by the machine.



THE MILL AND PRINTING PARTS OF BABBAGE'S ANALYTICAL ENGINE.

Constructed by Major-General H. P. Babbage, 1880-1910.

Note to Paper on Star Colours and Spectral Types.

By W. S. Franks.

In the *Monthly Notices*, vol. lxx. pp. 192–3 (observations of Southern Star Colours), there are several omissions, which I wish to rectify. I ought to have mentioned the estimates of star colours contained in various catalogues of "double" stars; such as Herschel's *Cape Observations*, and those by Dunlop (R.A.S. *Memoirs*, iii. 259), Jacob (*Memoirs*, xvi. 311 and xvii. 91), Russell (*Memoirs*, xlvi. 109), and Innes (*Monthly Notices*, lxi. 575; lxii. 470; and lxiii. 76). To the latter especially I have been indebted for the copious notes on star colours contained in the *M.N.*, and also in the great reference catalogue in vol. ii. of the *Cape Annals*; with a still later contribution in *Transvaal Observatory Circular*, No. 1.

And, quite inadvertently, no reference was made to the *Uranometria Argentina* as an authority on coloured stars. But, as is well known, the colour estimates of the Cordoba observers are somewhat exaggerated, and it requires some discrimination in dealing with them. Gould himself says "a large number of the stars to which an *r* is affixed are more nearly orange than red" (*U.A.*, p. 240). I have compared 103 of these with my own and other observers' estimates, with the following results:—18 are merely yellow, 39 orange-yellow, 44 orange, and only 2 orange-red. Hence the usual equivalent of *r* lies between orange-yellow and orange. For 7 stars marked *rr* (very red), 2 were orange-yellow, 3 orange, and 2 orange-red—orange being the mean equivalent. The stars marked *c* (coloured) are, on the whole, fairly expressed by yellow. Some notoriously white stars (according to spectral type, and other observers' estimates) are marked *r* in the *U.A.*; but possibly these may be traced to clerical errors or misidentification.

Uxbridge:
1910 *March* 28.